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Stand-Yield Prediction for Managed Ocala Sand Pine

D.L. Rockwood, B. Yang, and K.W. Outcalt

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Abstract

Sand pine is a very important species in Florida, producing significant quantities of fiber. The purpose of this study was to develop the site index and stand-level growth and yield equations managers need to make informed decisions. Data were collected from 35 seeded plots of Ocala sand pine covering a range of site indexes, ages, and densities in 1982-83. These plots were remeasured 5 and 10 years later and the data used to develop growth and yield equations by tree component. Equations for both current and future yields in volume and weight measures are given. These equations gave very good results when tested by comparing actual yields with predicted yields for a second set of 22 sand pine plantations measured in the panhandle area of Florida.

Keywords: Biomass, growth, site index, survival, yield.

Introduction

Sites with deep, sandy soils form a small but significant land resource [3.2 million hectares (ha)] in the Southeastern United States. The Choctawhatchee (*Pinus clausa* var. *immuginata* D.B. Ward) and Ocala (*P. clausa* var. *clausa*) varieties of sand pine grow naturally on these dry, sandy sites in northwestern and peninsular Florida, respectively. Many of the sandy sites in Florida, once occupied by low-quality scrub oaks generally unsuitable for forest products, have been converted to sand pine. Sand pine has also been extensively planted on sandy sites in Georgia and South Carolina (Burns 1973, Hebb 1981, McNab and Carter 1981, Preston and Price 1979).

Producers and managers are interested in expected growth and yield for these sand pine stands. Prediction equations for individual tree contents have been developed (McNab and others 1985, Rockwood and others 1987, Taras 1980), but equations for site index (SI) and stand-level yields from Ocala sand pine are not available. This paper presents equations developed to quantify SI, tree mortality, aboveground biomass, and growth and yield for Ocala sand pine stands in Florida.

Materials and Methods

Study Area

Ocala sand pine stands were randomly selected to represent a range of stand densities and ages (table 1). Most of the stands were less than 20 years old because few stands in the older age classes (20 to 40 years) could be located. The 35 stands in Marion County, located in the center of Florida on the Ocala National Forest, had originated from direct seeding after clearcutting or from natural regeneration. Planting had established the stands located in nearby Putnam and St. Johns Counties. Planted stands located in the panhandle area of west Florida made up the remainder of the sample.

Sand pine stands in the Ocala National Forest and those nearby in Putnam and St. Johns Counties were growing on Astatula or Paola sand soils (hyperthermic, uncoated Quartzipsamments). These soils consist of deep, droughty sand deposits from former dunes, offshore bars, and barrier

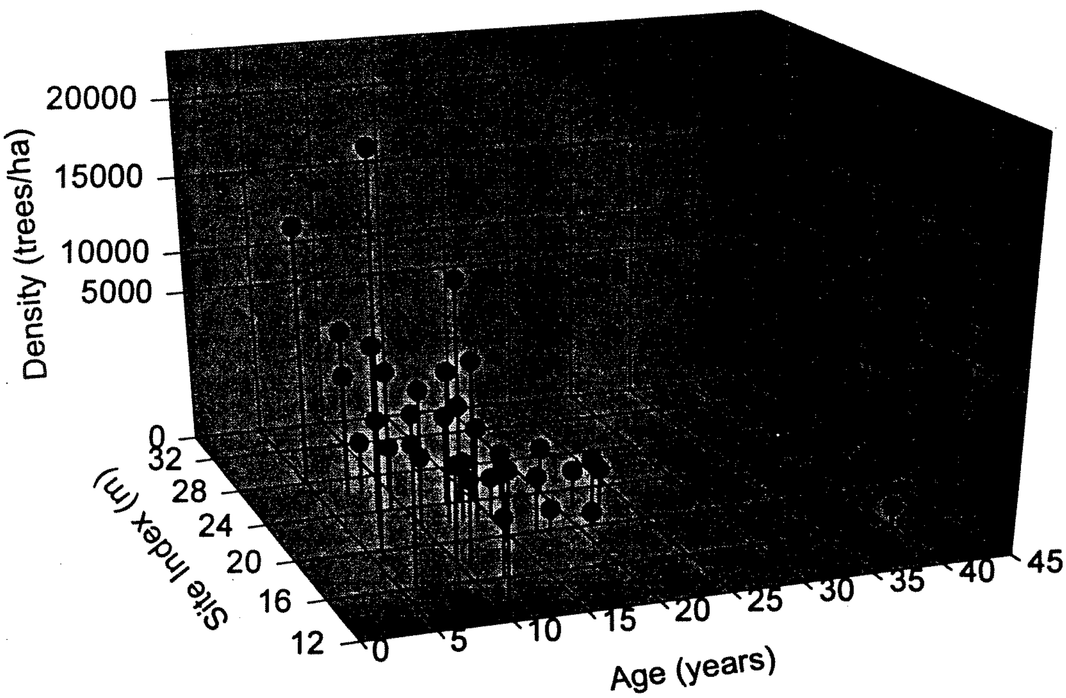
Table 1—Distribution of 57 Ocala sand pine biomass plots by initial age and location in Florida

Location (county)	Age (years) 5-10	11-15	16-20	21-25	36-40	Total
	Number of plots					
Bay	--	--	2	--	--	2
Gilchrist	--	1	--	--	--	1
Marion	14	12	4	4	1	35
Okaloosa	1	1	3	--	--	5
Putnam	2	--	--	--	--	2
St. Johns	--	--	3	--	--	3
Taylor	--	--	--	1	--	1
Walton	--	2	2	--	--	4
Washington	--	1	3	--	--	4
Total	17	17	17	5	1	57

Table 2—Coefficients for predicting current and future Ocala sand pine stand contents for 20 components[a]

	Equation parameters						
Component	a1	a2	a3	a4	a5	R^2	b
Stem wood							
Vol. I.B.	14.5109	-0.2159	0.3858	1.3508	-4.5843	0.9886	941.1
Green wt.	14.4191	- .2154	.3865	1.3428	-4.5938	.9842	1314.2
Dry wt.	13.6502	- .2156	.3863	1.3450	-4.5903	.9841	548.2
Stem bark							
Green wt.	12.2919	- .2115	.3914	1.3290	-4.6798	.9839	627.6
Dry wt.	11.7061	- .2118	.3910	1.3304	-4.6743	.9840	327.8
Stem							
Vol. O.B.	14.5251	- .2061	.3941	1.3236	-4.5986	.9871	1728.4
Green wt.	14.5317	- .2150	.3871	1.3462	-4.6081	.9843	1941.4
Dry wt.	13.7838	- .2151	.3870	1.3465	-4.6051	.9839	875.9
Branch wood							
Green wt.	13.4589	- .2122	.3906	1.3322	-4.6672	.9837	1739.3
Dry wt.	12.6711	- .2126	.3901	1.3345	-4.6581	.9839	706.2
Branch bark							
Green wt.	12.7434	- .2103	.3929	1.3226	-4.7021	.9833	700.4
Dry wt.	11.0706	- .2084	.3950	1.3132	-4.7323	.9820	319.5
Branch							
Green wt.	13.6998	- .2118	.3911	1.3301	-4.6754	.9840	2437.6
Dry wt.	12.8516	- .2119	.3911	1.3305	-4.6739	.9836	1025.6
Foliage							
Green wt.	12.6991	- .2033	.4004	1.2878	-4.7840	.9764	2506.5
Dry wt.	11.7446	- .2031	.4002	1.2867	-4.7853	.9762	982.0
Crown							
Green wt.	13.9931	- .2094	.3938	1.3184	-4.7164	.9828	4945.1
Dry wt.	13.1179	- .2096	.3936	1.3194	-4.7133	.9829	2007.5
Tree							
Green wt.	14.9283	- .2128	.3899	1.3352	-4.6556	.9839	6887.4
Dry wt.	14.1305	- .2131	.3895	1.3366	-4.6493	.9840	2883.5

Vol. I.B. = volume inside bark; Vol. O.B. = volume outside bark.
[a] $Y = a + \ln \{b * N + c * \exp [a1 + \ln (N)^{a2} + \ln (SI)^{a3} + \ln (B)^{a4} + a5 * \ln (1 / A)]\}$ with B in m^2, n in trees per hectare, $a = -13.8155$ and $c = 1$.



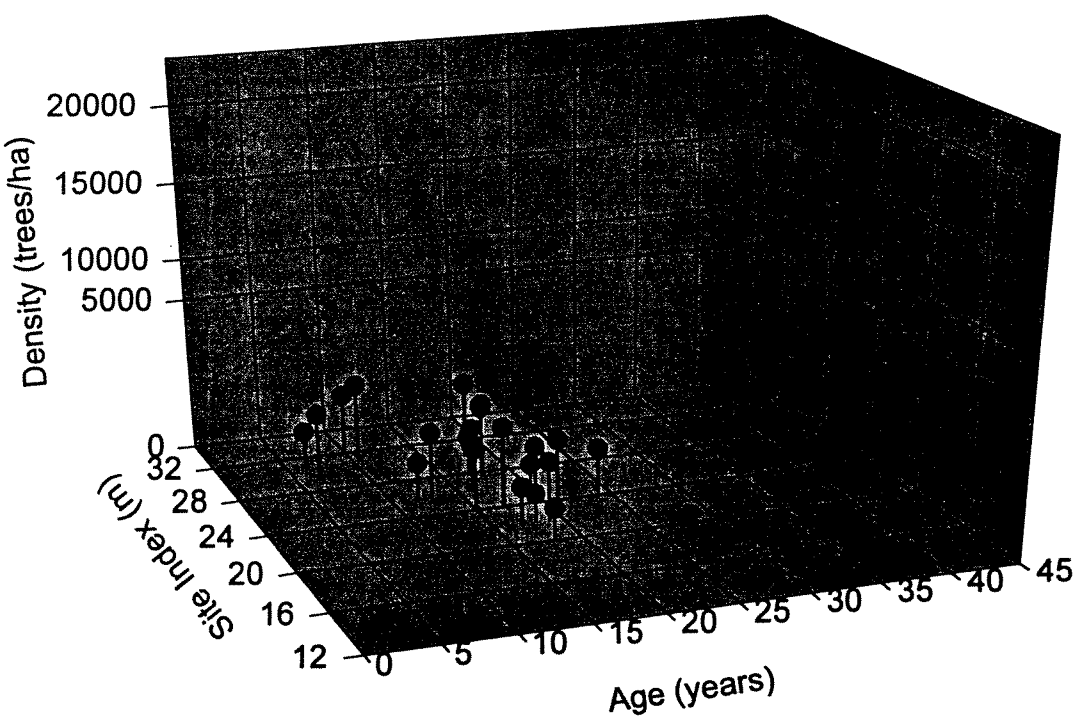


Figure 1—Distribution of seeded (top) and planted (bottom) Ocala sand pine plots by initial age, density, and site index.

The high R^2 is important because survival prediction is critical to accurate growth and yield prediction.

Figure 3 shows survival curves for six initial densities ranging from 1,100 to 18,000 trees per ha from ages 6 to 50. Survival is predicted to drop significantly for initial densities ≥ 12,000 such that by age 50 stand densities are near 4,000 trees per ha.

Basal area prediction—A simultaneous estimation procedure following techniques of Pienaar and others (1990) was used to estimate parameters in equations (11) and (12). Applying model (5), current sand pine basal area in m^2 per ha can be predicted:

$$B1 = \exp[-0.030 + \ln(SI)^{1.3915} + \ln(N)^{0.7487} - 16.9491 * (1 / A) - \ln(N1 * 1 / A)^{0.3357}] / 100 , \tag{11}$$

with $R^2 = 0.8263$, and future basal area (B2) can be projected:

$$B2 = B1 * \exp[-0.030 + \ln(SI)^{1.3915} + \ln(N2)^{0.7487} - 16.9491 * (1 / A2) - \ln(N2 * 1 / A2)^{0.3357}] / \exp[-0.030 + \ln(SI)^{1.3915} + \ln(N1)^{0.7487} - 16.9491 * (1 / A1) - \ln(N1 * 1 / A1)^{0.3357}] . \tag{12}$$

These two equations are compatible because the projection equation uses the same coefficients in a different form of the prediction equation. This ensures that the basal area projected at age $A2$ from the basal area at age $A1$ with equation (12) will be the same as the predicted basal area at age $A2$ given by equation (11) with $N2$ and SI. Figure 4 shows stand basal areas for six initial densities and four SIs.

Stand-level growth and yield equations—Stand average tree contents (Rockwood and others 1987) were successfully modeled as functions of stand basal area, SI, and age. For example, a stand's average tree SVOB (m^3) can be calculated:

$$\ln(SVOB) = -13.8155 + \ln\{1.728 * 10^3 + \exp[2.7610 + \ln(B)^{1.28766} + \ln(SI)^{0.4381} - 5.3366 * (1 / A) + \ln(N)^{0.06528}]\} , \tag{13}$$

with $R^2 = 0.986$
n = 3525.

Stand SVOB (SSVOB in m^3 per ha) (table 2) can then be calculated:

$$\ln(SSVOB) = -13.8155 + \ln\{1.728 * 10^3 * N + \exp[14.5251 - \ln(N)^{0.206} + \ln(SI)^{0.394} + \ln(B)^{1.323} - 4.5986 * (1 / A)]\} , \tag{14}$$

with $R^2 = 0.987$.

Using equation (14) in a simultaneous estimation procedure, the future SSVOB projection model was developed:

$$SSVOB2 = SSVOB1 * (\{1.728 * 10^3 * N2 + \exp[14.5251 - \ln(N2)^{0.206} + \ln(SI)^{0.394} + \ln(B2)^{1.323} - 4.5996 * (1 / A2)]\} / 1.728 * 10^3 * N1 + \exp[8.4808 - \ln(N1)^{0.206} + \ln(SI)^{0.394} + \ln(B1)^{1.323} - 4.5986 * (1 / A1)]\}) . \tag{15}$$

Stand growth and yield models can be applied to various basal areas, SIs, initial stand densities, and ages. For example, at SI = 28, stand volume ranged from 4 m^3 per ha at age 6 years and an initial density of 1,100 trees per ha to 319 m^3 per ha at age 50 with an initial density of 18,000 trees per ha at age 6 years (table 3, fig. 5). For SI = 24 at age-6 densities of 1,100 and 18,000 trees per ha, the expected yields are 85 m^3 per ha and 228 m^3 per ha at age 50 years, respectively. At SI = 16, stand volume ranged from 35 m^3 per ha to 99 m^3 per ha (N = 1,100 - 18,000) at age 50 years.

Model evaluation—Model (15) provided good estimates at the initial and at future ages. In the case of SSVOB, volumes predicted by model (15) were typically within 5 percent of the observed volumes. Using the actual data from the 35 Ocala National Forest plots to test the model:

$$P(SSVOB) = 7.3399 + 0.8767 * A(SSVOB) ,$$

with $R^2 = 0.9421$.

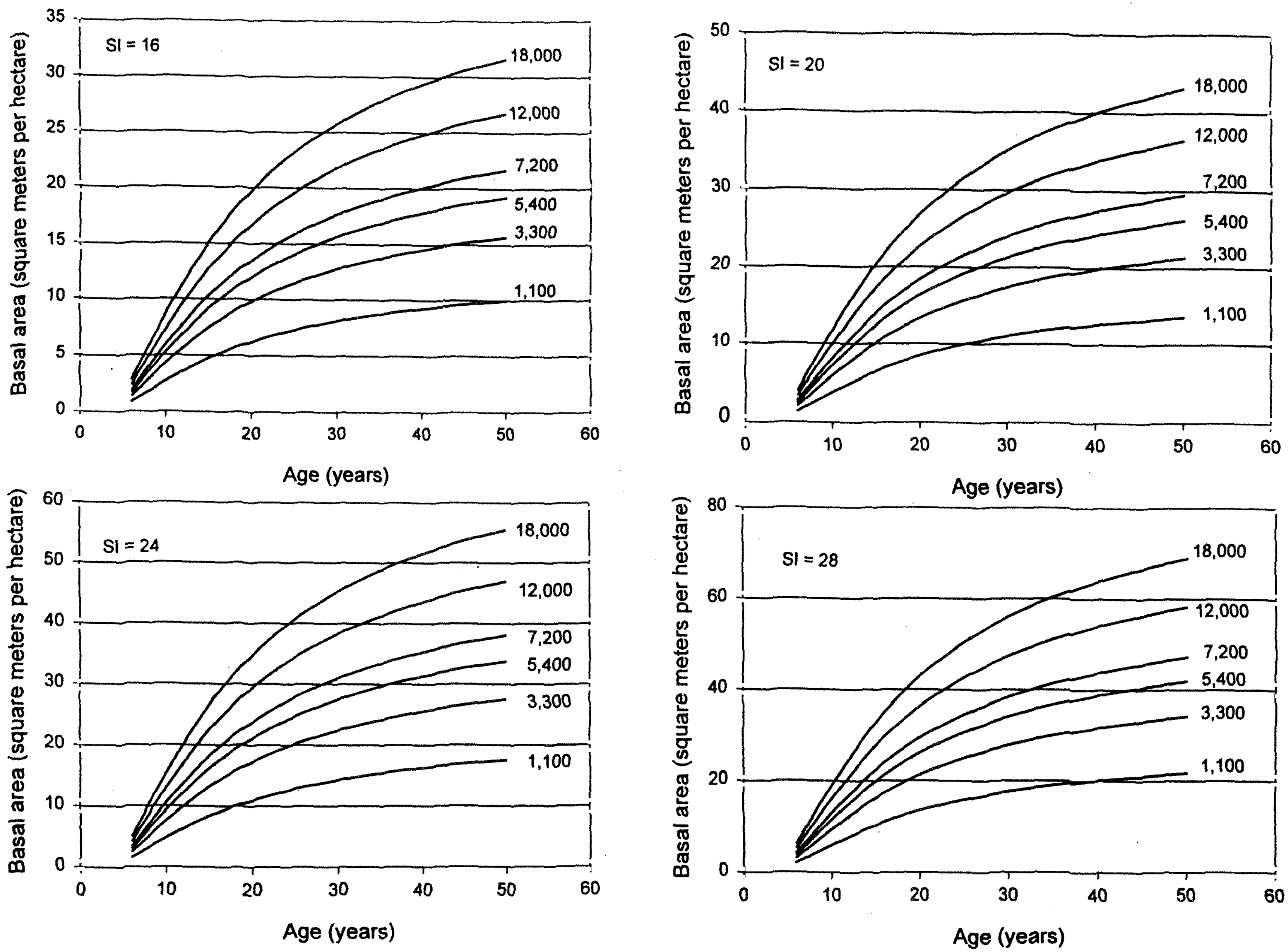


Figure 4—Stand basal area curves for Ocala sand pine at age-6 stand densities of 1 100, 3 300, 5 400, 7 200, 12 000, and 18 000 trees per hectare and site indices of 16, 20, 24, and 28 meters.

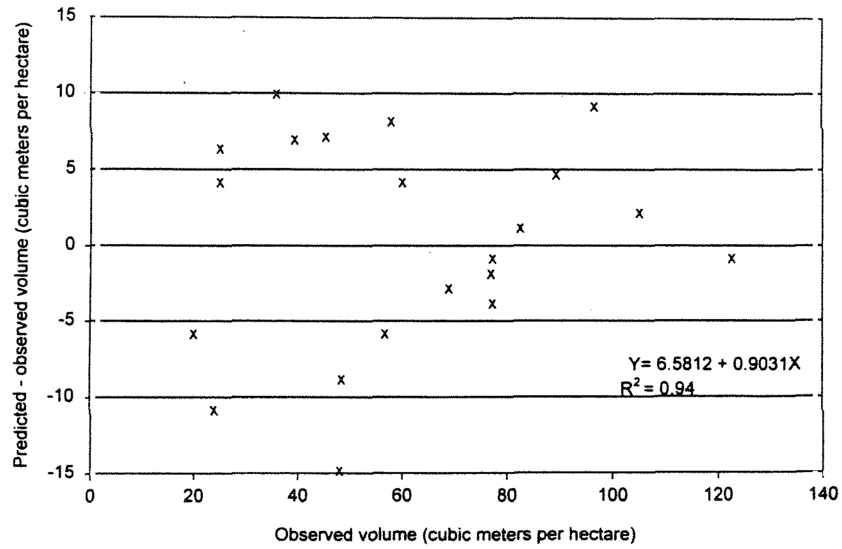


Figure 6—(Predicted-observed) versus observed volumes in Ocala sand pine plantation plots.

$$
\begin{aligned}
B2 = B1 * \exp[&4.5785 + \ln(28)^{1.3957} + \ln(4{,}408)^{0.7487} \\
&- 16.949 * (1/18) - \ln(4{,}408 * 1/18)^{0.3357}] / \\
\exp[&4.5785 + \ln(28)^{1.3945} + \ln(5{,}400)^{0.7487} \\
&- 16.949 * (1/12) - \ln(5{,}400 * 1/12)^{0.3357}]
\end{aligned}
$$

$= 31.0\ m^2$ per ha, and

$$
\begin{aligned}
\text{c) } SSVOB2 = \exp\big(&-13.8155 + \ln\{1.728 * 10^3 * 4{,}408 \\
&+ \exp[14.5251 - \ln(4{,}408)^{0.206} + \ln(28)^{0.394} \\
&+ \ln(31.0)^{1.323} - 4.5986 * (1/18)]\}\big)
\end{aligned}
$$

$= 105.2\ m^3$ per ha.

For different management objectives, the best stand option can be selected based on these yield predictions.

Equation (6) can be used to predict stand contents for all traits that can be predicted on an individual tree basis, i.e., the 20 volumes and weights in table 2. By combining volumes and weights with energy values (Rockwood and others 1980), stand energy components can be estimated. These estimates reflect stand yields possible with the seed sources used for direct seeding or nursery propagation until the late 1970's; improved seed could result in different patterns of stand development (Rockwood and Goddard 1980).

The equations in table 2 have been incorporated into a computer spreadsheet to facilitate yield projections. By specifying initial stand condition and future ages, current and future growth and yield may be readily calculated (table 4). Table 5 displays in English format, current and projected yields for a range of SIs and initial densities. D.L. Rockwood (senior author) will provide a QUATTRO, LOTUS, or EXCEL version of the spreadsheet for yields in metric format, and K.W. Outcalt, the third author, will provide a LOTUS or EXCEL version in English format.

Acknowledgments

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Table 5a—Stem volume and weight for managed Ocala sand pine stands by site index 50, age, and density

Age	Density	Basal area	Stem volume OB	Stem volume IB	Stem weight Green	Stem weight Dry
	Trees/ac	*Ft²*	- - - *Ft³* - - -		- - - - - *Lb* - - - - -	
12	405	18	118	101	7,292	3,413
16	350	26	187	169	11,501	5,410
20	313	31	254	234	15,606	7,357
24	286	36	314	294	19,333	9,124
28	265	40	368	347	22,634	10,689
32	248	42	414	393	25,540	12,066
36	234	45	455	434	28,100	13,280
40	222	47	492	470	30,364	14,353
44	211	48	524	502	32,377	15,307
48	202	50	552	531	34,175	16,159
12	607	22	144	120	8,982	4,193
16	526	30	222	198	13,734	6,450
20	470	37	298	273	18,392	8,661
24	429	43	367	341	22,629	10,671
28	397	47	428	401	26,388	12,453
32	372	50	481	454	29,699	14,024
36	350	53	528	501	32,618	15,407
40	332	55	569	543	35,199	16,631
44	317	57	606	579	37,494	17,720
48	303	59	639	612	39,546	18,692
12	809	24	167	137	10,506	4,295
16	701	34	252	222	15,667	7,349
20	627	42	335	305	20,750	9,762
24	572	48	411	380	25,384	11,961
28	530	53	477	446	29,499	13,914
32	495	57	536	504	33,126	15,634
36	467	60	587	556	36,324	17,151
40	443	62	632	601	39,154	18,493
44	422	65	673	642	41,670	19,687
48	404	66	708	678	43,920	20,754
12	1,012	27	189	153	11,928	5,550
16	876	38	280	244	17,418	8,161
20	783	46	368	332	22,849	10,741
24	715	53	449	413	27,809	13,096
28	662	58	520	484	32,218	15,189
32	619	62	583	547	36,107	17,034
36	584	65	638	602	39,537	18,661
40	554	68	687	651	42,573	20,102
44	528	71	730	695	45,273	21,383
48	506	73	769	734	47,688	22,528

OB = outside bark; IB = inside bark.

Table 5b—Stem volume and weight for managed Ocala sand pine stands by site index 55, age, and density

Age	Density	Basal area	Stem volume OB	Stem volume IB	Stem weight Green	Stem weight Dry
	Trees/ac	*Ft²*	- - - *Ft³* - - -		- - - - - *Lb* - - - - -	
12	404	21	139	121	8,619	4,041
16	350	29	226	206	13,891	6,542
20	313	36	309	288	19,017	8,971
24	285	41	384	362	23,663	11,174
28	264	45	451	428	27,776	13,123
32	247	48	509	485	31,395	14,838
36	233	51	560	536	34,583	16,349
40	221	53	605	581	37,400	17,684
44	211	55	644	621	39,905	18,871
48	202	57	680	657	42,143	19,932
12	600	25	168	144	10,455	4,891
16	520	35	266	240	16,410	7,718
20	465	42	360	333	22,223	10,475
24	424	48	446	418	27,501	12,978
28	393	53	521	493	32,178	15,195
32	367	57	587	559	36,296	17,147
36	346	60	645	617	39,923	18,867
40	329	63	696	668	43,131	20,387
44	313	65	742	713	45,982	21,739
48	300	67	782	754	48,531	22,947
12	800	28	194	163	12,122	5,662
16	693	39	301	269	18,612	8,744
20	620	48	404	371	24,969	11,760
24	566	54	498	464	30,751	14,503
28	524	60	580	547	35,879	16,935
32	490	64	653	619	40,395	19,077
36	462	68	716	683	44,376	20,964
40	438	71	773	739	47,896	22,633
44	418	73	822	789	24,117	18,258
48	400	75	867	834	53,824	25,444
12	1,000	30	217	180	13,665	6,373
16	866	43	332	294	20,589	9,663
20	774	52	442	404	27,395	12,894
24	707	60	543	504	33,594	15,836
28	654	66	631	593	39,096	18,446
32	612	70	709	671	43,945	20,746
36	577	74	778	740	48,219	22,773
40	547	78	838	800	52,001	24,566
44	522	80	892	854	55,363	26,161
48	500	83	940	903	58,369	27,587

OB = outside bark; IB = inside bark.

Table 5e—Stem volume and weight for managed Ocala sand pine stands by site index 70, age, and density

Age	Density	Basal area	Stem volume OB	Stem volume IB	Stem weight Green	Stem weight Dry
	Trees/ac	*Ft²*	- - - -*Ft³*- - - -		- - - - - -*Lb*- - - - - -	
12	400	29	221	199	13,565	6,382
16	346	41	371	347	22,804	10,762
20	310	50	515	489	31,737	14,995
24	283	57	645	617	39,816	18,822
28	262	63	759	730	46,958	22,206
32	245	68	859	830	53,238	25,181
36	231	71	947	918	58,765	27,800
40	219	74	1,024	995	63,651	30,115
44	209	77	1,093	1,064	67,991	32,171
48	200	79	1,154	1,126	71,870	34,009
12	600	34	262	234	16,182	7,602
16	520	48	434	402	12,596	10,317
20	465	59	598	565	36,918	17,433
24	424	68	746	712	46,155	21,810
28	393	74	877	842	54,327	25,683
32	367	80	991	957	61,514	29,088
36	346	84	1,092	1,057	67,841	32,087
40	329	88	1,180	1,146	73,434	34,737
44	313	91	1,259	1,225	78,404	37,092
48	300	94	1,329	1,296	82,845	39,196
12	800	39	298	262	18,440	8,652
16	693	54	485	448	29,976	14,124
20	620	67	666	627	41,178	19,435
24	566	76	829	789	51,326	24,245
28	524	84	973	932	60,309	28,503
32	490	90	1,098	1,058	68,211	32,248
36	462	95	1,209	1,169	75,169	35,546
40	438	99	1,306	1,267	81,320	38,461
44	418	103	1,393	1,354	86,787	41,052
48	400	106	1,470	1,432	91,672	43,367
12	1,000	42	329	288	20,482	9,600
16	866	60	531	487	32,851	15,469
20	774	73	725	680	44,884	21,175
24	707	84	900	855	55,795	26,348
28	654	92	1,055	1,009	65,457	30,928
32	612	99	1,190	1,145	73,958	34,958
36	577	104	1,309	1,265	81,445	38,507
40	547	109	1,414	1,370	88,065	41,645
44	522	112	1,507	1,464	93,949	44,434
48	500	116	1,590	1,548	99,207	46,926

OB = outside bark; IB = inside bark.

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